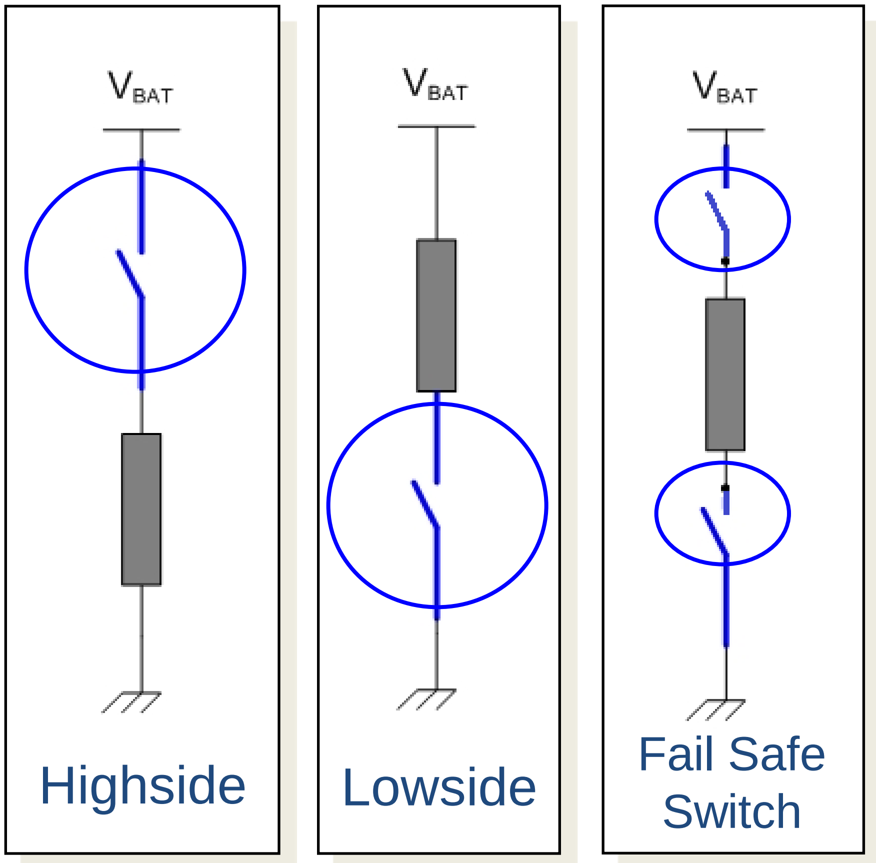
PROFET+:
High Side Switch

Infineon Technologies

PROFET™ = Protected High-Side Switches
Basic Design in Power Electronics

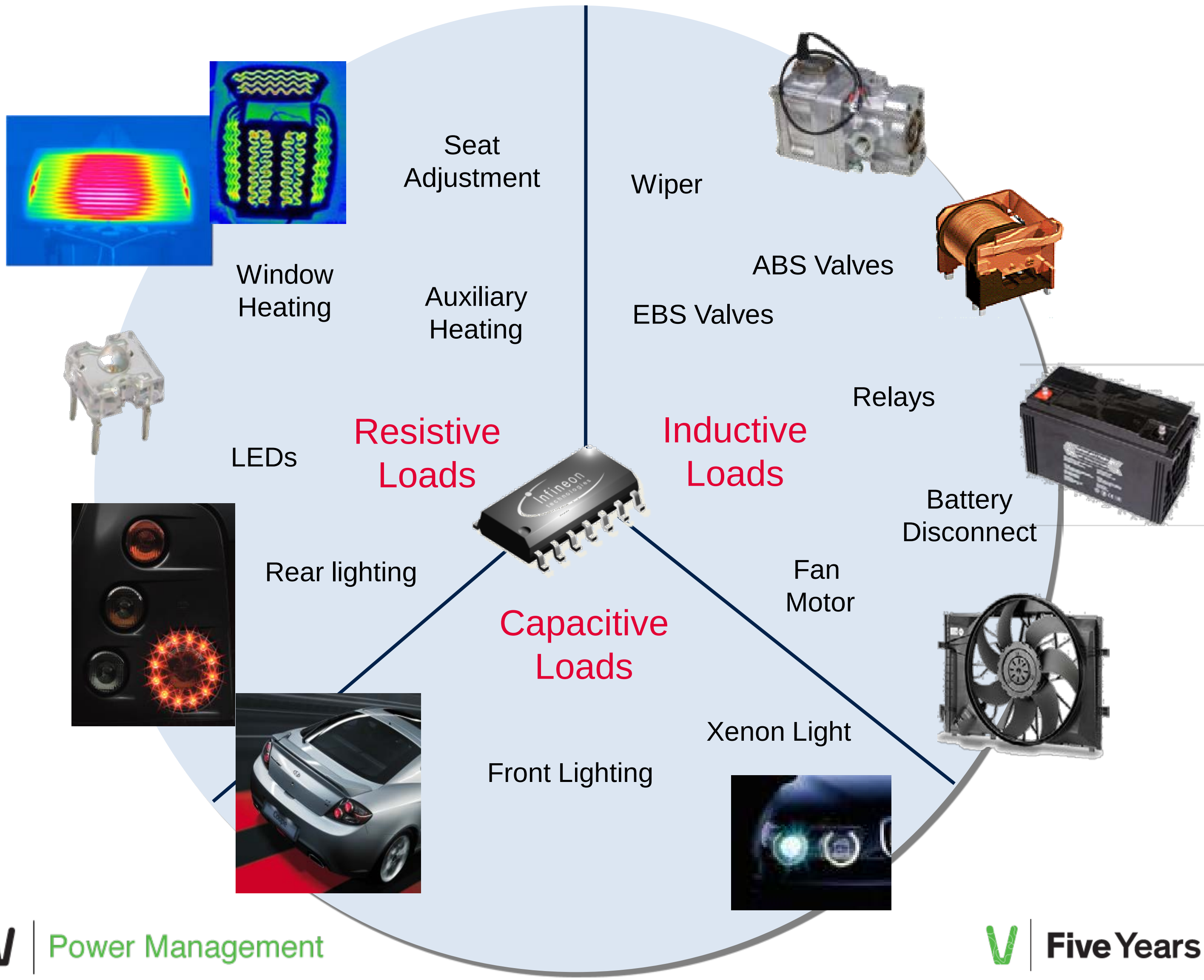


High-Side:
- Switch is placed between supply and load

Low-Side:
- Switch is placed between load and ground

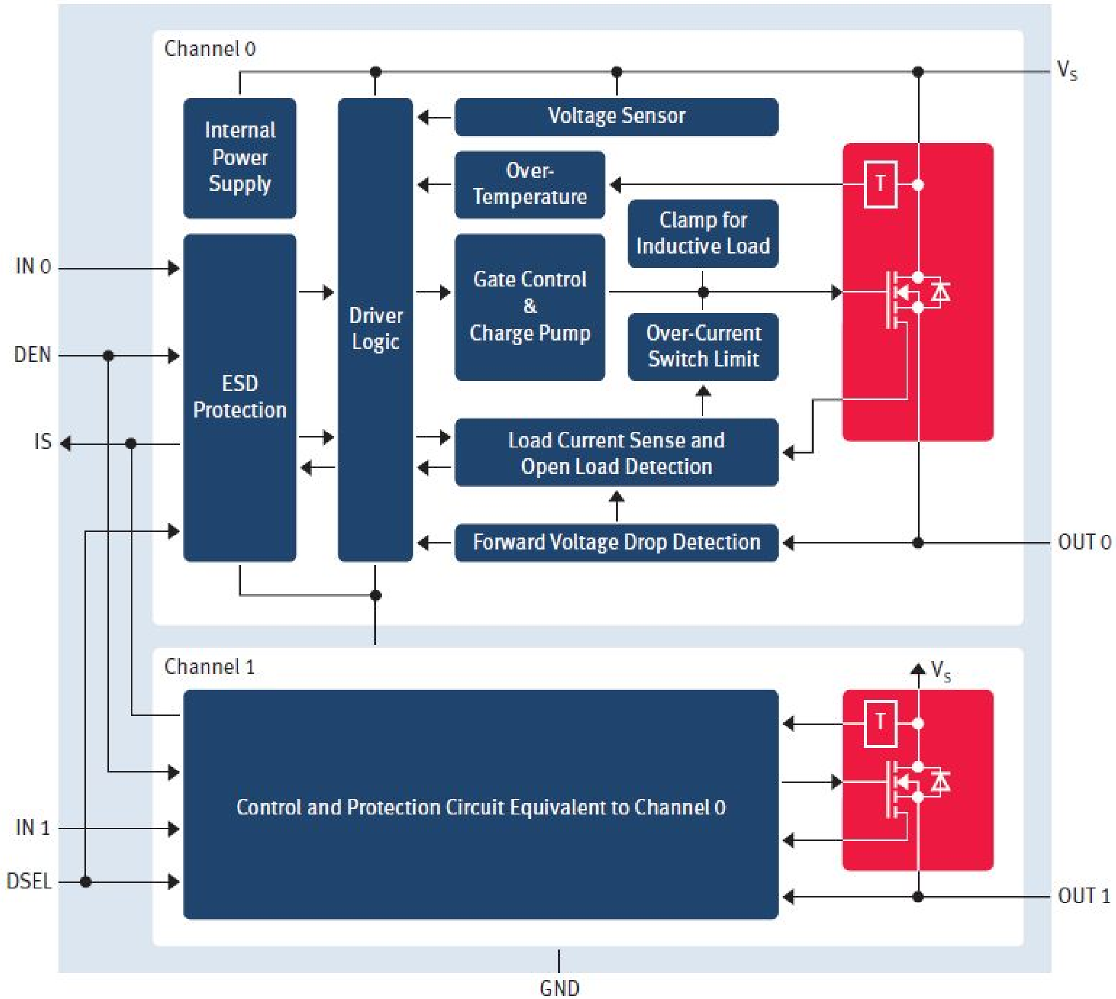
High-Side Advantages:
- Protected wiring harness
- Load disconnected from supply in OFF state
- No electrical galvanic corrosion (vs. relay)
- Reduced system cost (smaller diameter wires)

PROFET^{TM} Application Range



PROFET™+ 12V Family: Overview

2 channel



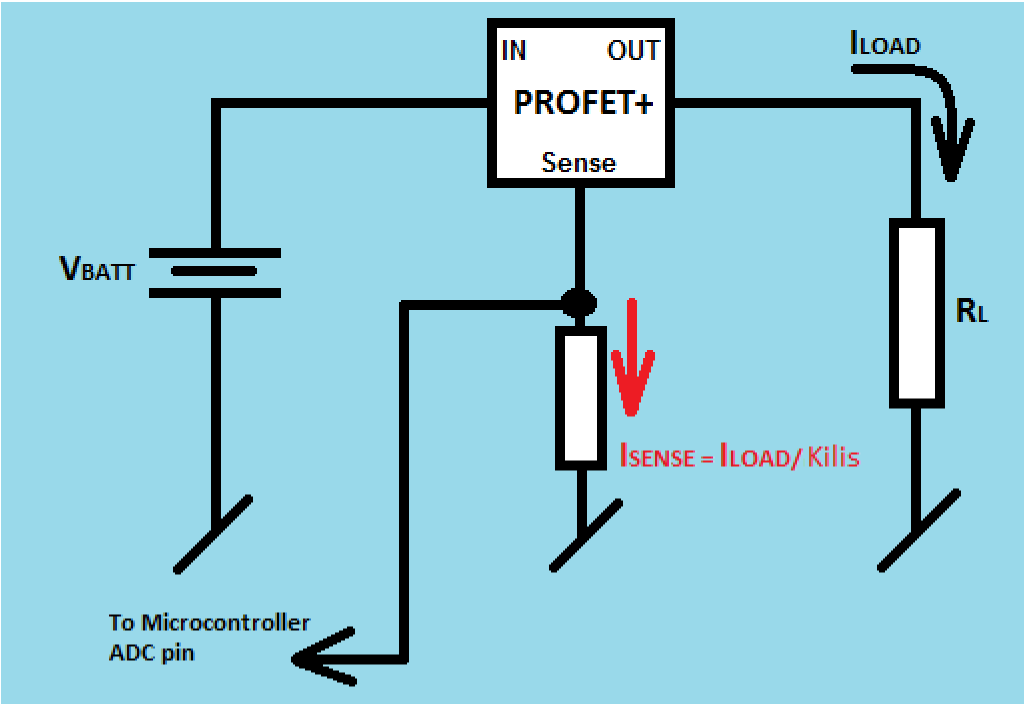
Protective Functions:

- Short circuit protection
- Over-load protection
- Current limitation
- Thermal shutdown with auto-restart
- Over-voltage protection (incl. load dump)
- Loss of ground protection
- Loss of VS protection (with ext. diode for charged inductive loads)
- ESD protection

Diagnostic Functions

- Proportional load current sense with defined fault signal in case of overload operation, over temperature shutdown and/or short circuit shutdown
- Open load detection in ON-state by load current sense, in OFF-state by fault flag
- Current sense can be enabled/ disabled for easy multiplexing and decreased use of µC A/D ports

PROFET+ Current Sense



- The HS Switch provides a sense current proportional to the load current
- The accuracy of the sense current depends on temperature and load current
- The sense pin is also used to signal faults to the microcontroller in ON state (Over Load and Over Temperature) and in OFF state conditions (Open Load, Short-to-Battery & Reverse Current).

K_{ilis} Accuracy at Nominal Current Levels

- Best-in-class sense accuracy specified *without calibration*
- Tolerance includes drift over production *and* temperature

BTS 5020-2EKA 2x20 mohm device

Current Sense Ratio Signal in the Nominal Area, Stable Load Current Condition

Current sense ratio I_{L0} = 50 mA	k_{ILIS0}	-50	3600 Kilis	+50	%	V_{IN} = 4.5 V V_{DEN} = 4.5 V See Figure 21 T_J = -40 °C; 150 °C
Current sense ratio I_{L1} = 0.5 A	k_{ILIS1}	-34	3000	+34	%	
Current sense ratio I_{L2} = 2 A	k_{ILIS2}	-8	3000	+8	%	±5 %
Current sense ratio I_{L3} = 4 A	k_{ILIS3}	-7	3000	+7	%	
Current sense ratio I_{L4} = 7 A	k_{ILIS4}	-5.5	3000	+5.5	%	
k_{ILIS} derating with current and temperature	Δk_{ILIS}	-5	0	+5	%	[3] k_{ILIS3} versus k_{ILIS2} See Figure 22

- With single-point calibration (measure at k_{ILIS3} at room temperature), *Infineon guarantees +/-5% accuracy over the nominal range*

PROFET™+ Protection Mechanisms

- **Current Limitation** – The device limits the current to below the maximum acceptable current value. Meanwhile, the device heats up until reaching the overtemperature limit, at which point it switches off
- **Absolute Temperature Limitation** – All PROFET™+ devices have absolute thermal tripping at 150˚C min, 170˚C typical
- **Dynamic Thermal Tripping** (or Delta T tripping) uses two temperature sensors per channel to limit the rate of temperature rise during a short. One sensor is placed at the hotspot of the die where there is the highest current density, another sensor is in the logic section which remains cooler during activation, and the delta between the two sensors is monitored
- Once the device is tripped by Absolute Temperature Sensor or Delta T -
  - ❑ **PROFET™+ 12V** devices will **restart automatically** after cooling down to an acceptable level
  - ❑ **PROFET™+ 24V** devices will **latch-off**, requiring the input pin to be toggled

- **Loss of ground protection** – Devices will turn off in the case of loss of ground
- **Overvoltage protection –** Includes clamping for load dump
- **Undervoltage shutdown –** Compatible with vehicle cranking requirements

Process to choose the correct PROFET+ device

- **STEP 1: Questions for the Customer:**
  - **What is the load type?**
    - **Resistive:** What is the max DC load current? (Example-heating elements)
    - **Capacitive:** Wh… rent? What is the inrush current? (Example- incandescent bul…
    - **Inductive:** What … ent? What is the resistance and inductance of the load? (Exa…

  - **What is ambient te… module and estimated temperature rise insid…**
    - Many times for a plas… mon to have approximately a 20°C rise inside the box compa…

Process to choose the correct PROFET+ device

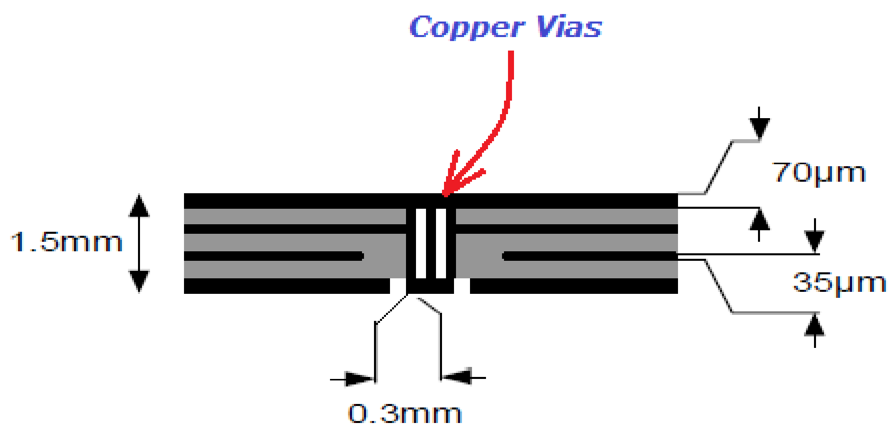
- **STEP 1: Questions for the Customer: (cont.)**
  - **What is the maximum static temperature the PCB is rated for?**
    - Quite often FR-4 material is rated to 130-135ºC
  - **Will the application use PWM?**
    - If yes what is the PWM frequency? / Min duty cycle? / Max duty cycle?

Delamination!

Switching Losses

Process to choose the correct PROFET+ device

- **STEP 1: Questions for the Customer: (cont.)**
  - **How much PCB copper area will be connected to the exposed pad (Vbatt connection) for thermal cooling?**
    - This is important to estimate a thermal resistance junction-ambient for surface mounted devices (Rthja)
    - Typically the industry uses the following standards:
      - » Jedec 2s2p: 4 layer PCB with full inner layer cooling plane with thermal vias to package tab (commonly found in PROFET+ datasheet)
      - » Jedec 1s0p: Single layer PCB with minimum Cu footprint required only for
      - » Cu cooling area connected
      - » u cooling area connected



2s2p PCB Cross Section

Process to choose the correct PROFET+ device

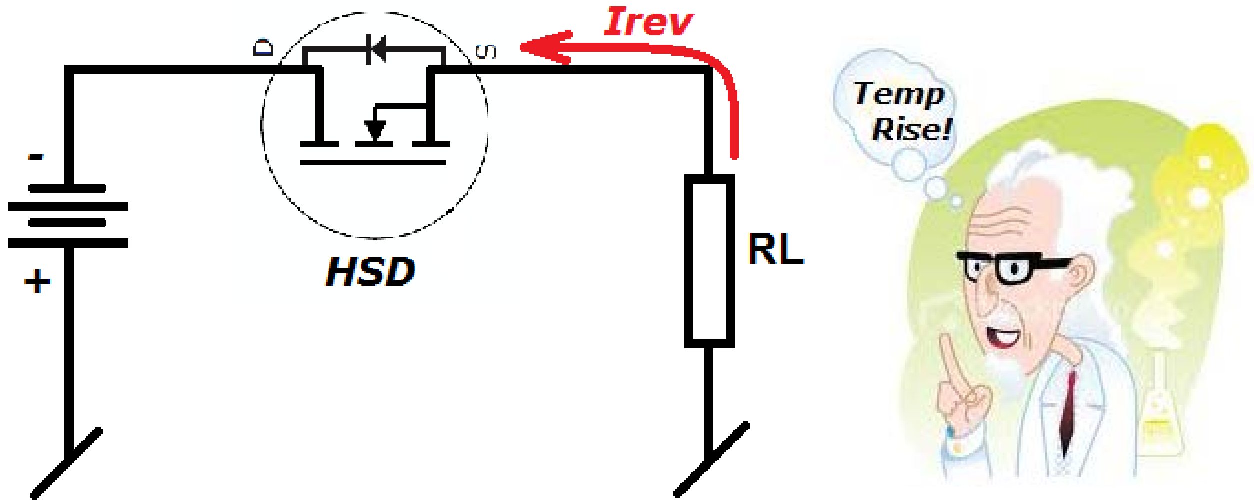
- **STEP 1: Questions for the Customer: (cont.)**

  - **What battery voltage should the analysis be done at? What voltage were the DC currents defined at?**
    - Many times the load currents are define at 12.8V or 13.2V but the analysis is to be done at the worst case voltage of 16V. For these cases the current must be scaled from the definition voltage to the analysis voltage.

Process to choose the correct PROFET+ device

- **STEP 1: Questions for the Customer: (cont.)**

  - **Will the PROFET+ devices be subjected to reverse battery tests?**
    - If yes, what are test parameters? (Ambient temperature? / Time? / Reverse voltage?)
    - What is the pass/fail criteria?



Process to choose the correct PROFET+ device

- **STEP 2: Determine device temperature rise that is acceptable for the application**
  - **Given:**
    - Ambient temperature inside module is X-^{o}C (data from customer)
    - Maximum allowable device junction temperature is 150^{o}C (datasheet max rating)
    - Maximum allowable PCB temperature is Y-^{o}C (data from customer)---***We can make an assumption that PCB temperature is ≈ the same temperature as the junction temperature. PROFET+ is in exposed pad package and has low thermal resistance from junction to exposed pad***
  - Example:
    - Ambient temperature inside module is 105^{o}C.
    - Maximum allowable PCB temperature is 135^{o}C
    - Maximum junction temperature is 150^{o}C
    - ***Thus: junction temperature is allowed to increase*** *30^{o}C*

Process to choose the correct PROFET+ device

- **STEP 3: Determine what junction-ambient thermal resistance should be assumed for the application**
  - Some guidelines for PROFET+ in exposed pad packages:
    - Jedec 2s2p is multi-layer PCB with inner layer as complete cooling plane
    - Jedec 1s0p is single layer PCB with X-cm^2 Cu cooling area

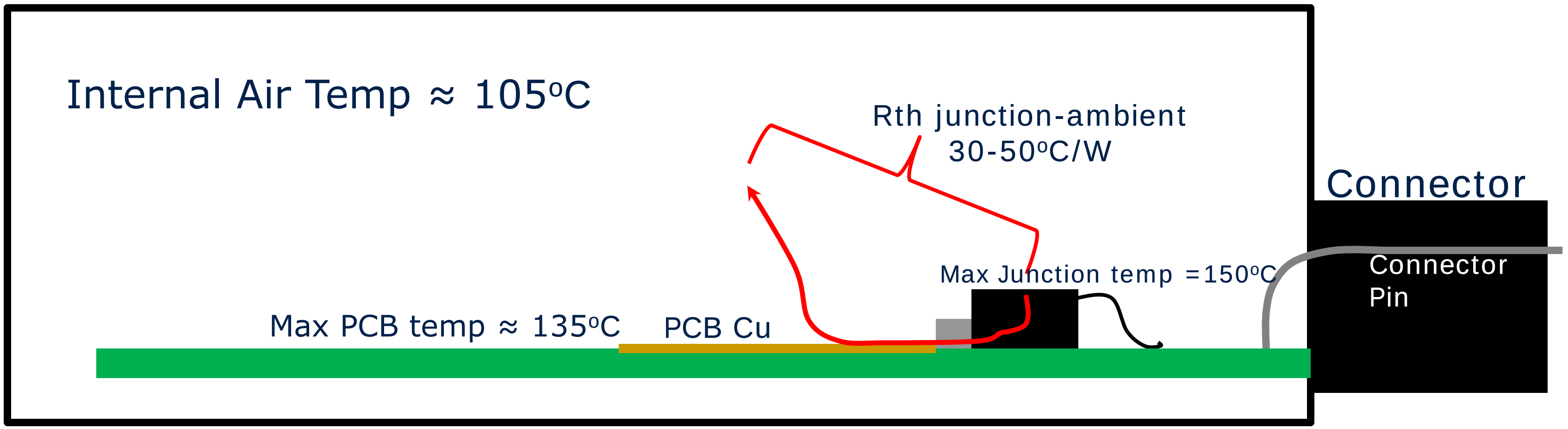
Device	PCB Scenario		
	Jedec 2s2p	Jedec 1s0p + 6cm^2 Cu	Jedec 1s0p + 3cm^2 Cu
BTS5120/5180-2EKA	37degC/W	44degC/W	50degC/w
BTS5020-2EKA	30	38	44
BTS5045/5090-1EJA	40	47	52
BTS5020-1EKA	37	42	48
BTS5008-1EKA	30	38	44

From Datasheet

Additional Information

Thermal Assumptions/Example
Plastic Box Construction

Ambient Air
Temp = 85ºC



Thus here if we have an air temp inside the box of 105ºC and the max PCB temp is 135ºC we can allow the junction to rise 30ºC (using assumption that PCB temp is approximately same as junction temperature

Process to choose the correct PROFET+ device

- **STEP 4: Determine how to scale load current**
  - Many times the load current is defined at a certain voltage but the analysis is to be done at a different voltage.
  - Example: Load definition is 5A at 12.8V but analysis is to be done at 16V.
  - How to scale load current definition to the analysis voltage?
    - Ohmic/Inductive/LED load: we can assume a linear relationship
      - » $I_{application} = I_{definition} * (V_{application}/V_{definition})$
    - Example: $I_{application} = 5 * (16/12.8) = 6.25A$
    - Bulb load: current thru bulb is a function of filament temperature and the relationship of filament resistance to filament temperature is not linear
    - The relationship is approximated by an exponential of 0.5505
      - » $I_{application} = I_{definition} * (V_{application}/V_{definition})^{0.5505}$
    - Example: $I_{application} = 5 * (16/12.8)^{0.5505} = 5.65A$

Process to choose the correct PROFET+ device

- **STEP 5: Determine what power dissipation can be allowed in the particular application**
  - Choose a thermal resistance value based on customer feedback of PCB layout and type of device (single channel/dual channel, Rdson) most likely to be used
  - For an ***initial assumption*** we can use the following:
    - Jedec 2s2p: 35ºC/W
    - Jedec 1s0p + 6cm^2: 40ºC/W
    - Jedec 1s0p + 3cm^2: 50ºC/W
  - Example: From slide #9 we are allowed a temperature rise of 30ºC and we have a PCB cooling area approximated to Jedec 1s0p+6cm^2 Cu area

$$P_{Diss} = \frac{\Delta_{TEMP}}{R_{thja}} = \frac{30^o C}{40^o C/W} = 0.75W$$

» **This is per package power, not channel power**

- This step may need to be iterated after a final choice is made---need to make sure the Rthja assumption made above was a good estimation (within 10%) of the Rthja from actual device chosen

Process to choose the correct PROFET+ device

- **STEP 6: Determine device Rdson required for application**
  - Total Power dissipation is a combination of conductive losses and switching losses
  - Conductive losses: $P_{RDSon} = I^2_{LOAD} * R_{DSON} * D$
  - Switching losses: $P_{switching} = F_{PWM} * (E_{on} + E_{off})$
    - The datasheet specifies the turn on and off energy at 3 different voltages & over temperature.
    - Use linear scaling for Eon and Eoff!

9.2.9 Switch OFF Energy

P_5.5.20

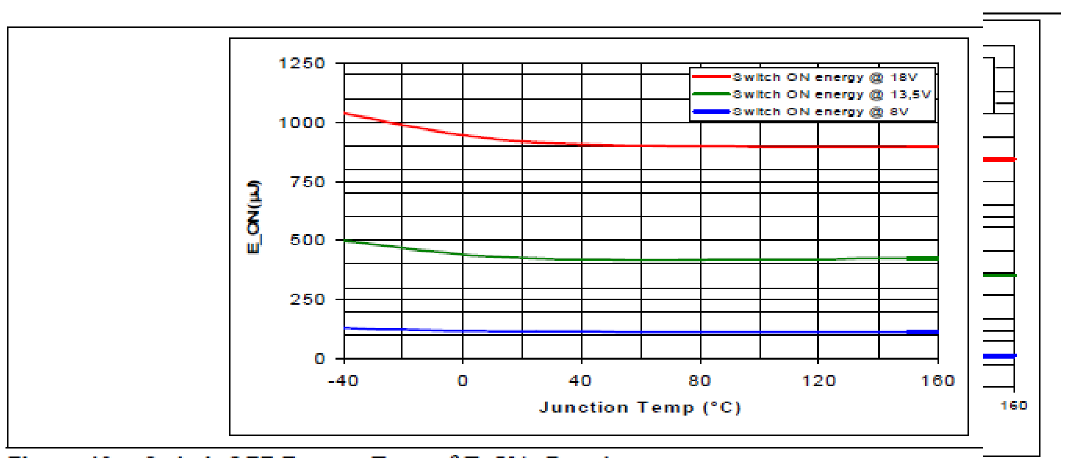


Figure 42 Switch OFF Energy $E_{OFF} = f(T_J;V_S)$, R_L = 4 Ω

Process to choose the correct PROFET+ device

- **STEP 6: Determine device Rdson required for application (cont)**
  - Total power:
    - Typically the switching losses become significant at ≈ 100Hz. The switching losses at 1Hz flasher application are not significant and can be ignored (but duty cycle is still 50%!!)

$$P_{total} = I_{LOAD}^2 * R_{DSON} * D + F_{PWM} * (E_{on} + E_{off})$$

$$R_{DSONmax} = \frac{(P_{allowed} - F_{PWM} * (E_{on} + E_{off}))}{I_{LOAD}^2 * D}$$

$$R_{DSONmax} = \frac{P_{allowed}}{I_{LOAD}^2}$$ No PWM!

  - This $R_{dsonmax}$ is the value at 150°C, 25°C value will be half.

Process to choose the correct PROFET+ device

- **STEP 6: Determine device Rdson required for application (cont):**
    - General tips on how to handle partitioning between dual channel devices and single channel devices
        - Generally similar load currents can be put onto a dual channel device (all PROFET+ dual channel devices have same Rdson for both channels).
        - Thus power dissipation for each channel should be approximately half the allowable package dissipation
        - Generally dissimilar load currents are put on different devices, not onto a dual device with the same Rdson for each channel
        - Example: Customer has 2x2A loads and 1x5A load
            - » Generally the solution would be to put the 2x2A loads on a dual channel device and the 5A load separately on a single channel device

Process to choose the correct PROFET+ device

- **STEP 7*: Initial* choice based on allowable power dissipation and Rdson**
    - Below tables give Rdson at 25^{o}C which is one half of max Rdson at 150^{o}C

high ohmic duals		
BTS 5020-2EKA	SO-14 EP	2x20
BTS 5030-2EKA		2x30
BTS 5045-2EKA		2x45
BTS 5090-2EKA		2x90
BTS 5120-2EKA		2x120
BTS 5180-2EKA		2x180

high ohmic singles		
BTS 5030-1EJA	SO-8 EP	1x30
BTS 5045-1EJA		1x45
BTS 5090-1EJA		1x90

high ohmic quad		
BTS 5200-4EKA	SO-14 EP	4x200

low ohmic singles		
BTS 5008-1EKB	SO-14 EP	1x8
BTS 5010-1EKB		1x10
BTS 5012-1EKB		1x12
BTS 5016-1EKB		1x16
BTS 5020-1EKA		1x20

low ohmic duals		
BTS 5008-2LAA	VSON 14 EP	2x8
BTS 5010-2LAA		2x10
BTS 5012-2LAA		2x12
BTS 5016-2LAA		2x16

Process to choose the correct PROFET+ device

- **STEP 8: Finalize choice with a cross check of requirements for:**
  - Capacitive Loads: In-rush current
  - Inductive Loads: Turn-off energy
  - All applications: Reverse Battery

Process to choose the correct PROFET+ device

- **STEP 8: Finalize choice with a cross check of requirements for (cont.):**
  - **Capacitive Loads:** The inrush current requirements must be checked with capacitive loads such as incandescent bulbs.
  - A good rule of thumb is that the PROFET+ device should have a minimum current limiting level that is equal to or greater than the maximum inrush current of the load at nominal conditions.

Overload Condition						
Load current limitation	$I_{LS(SC)}$	50	65	80	A	3) V_{DS} = 5 V See **Figure 18** and **Figure 43**

  - More precisely—check appnote for PROFET+ lamp driving capability. Table-5 on page 15 gives a good summary with green and yellow being acceptable (able to turn on lamp in < 10msec) and red is not acceptable (lamp turn on > 10msec).

Process to choose the correct PROFET+ device

- **STEP 8: Finalize choice with a cross check of requirements for (cont):**
  - **Inductive loads:** The turn off energy created by the inductive load must be checked against the energy handling capability of the PROFET+ device.
  - Each PROFET+ datasheet gives an equation on how to calculate the load energy and a graph of the device handling capability
  - NOTE: This graph is only for a singe lifetime pulse. For repetitive lifetime usage such as turning off a relay coil a good estimate is to use half of the single pulse energy and please consult the IFX technical contact.

$$E = V_{DS(AZ)} \times \frac{L}{R_L} \times \left[\frac{V_S - V_{DS(AZ)}}{R_L} \times \ln\left(1 - \frac{R_L \times I_L}{V_S - V_{DS(AZ)}}\right) + I_L\right] \quad (1)$$

Following equation simplifies under the assumption of $R_L = 0\ \Omega$.

$$E = \frac{1}{2} \times L \times I^2 \times \left(1 - \frac{V_S}{V_S - V_{DS(AZ)}}\right) \quad (2)$$

The energy, which is converted into heat, is limited by the thermal design of the component. See **Figure 11** for the maximum allowed energy dissipation as a function of the load current.

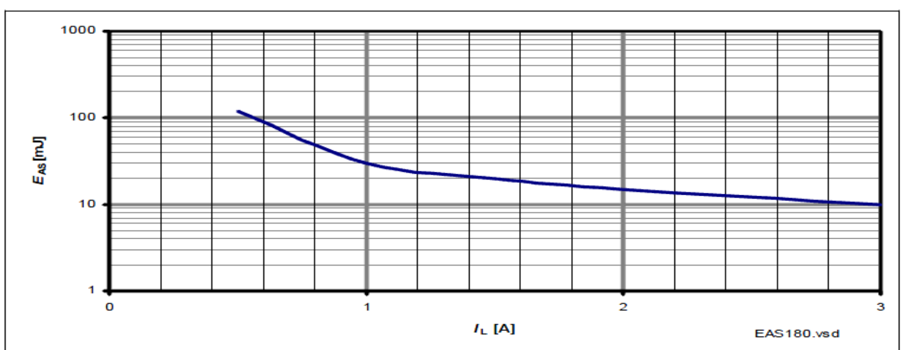


Figure 11 Maximum Energy Dissipation Single Pulse, T_{J_START} = 150 °C; V_S = 13.5V

Process to choose the correct PROFET+ device

- **STEP 8: Finalize choice with a cross check of requirements for:**
  - **Reverse Battery:** PROFET+ devices do NOT have ReverseSave, another words they do NOT turn on during reverse battery and all the current flow is through the device intrinsic body diode.
  - Thus the device power dissipation during reverse battery $P_{rev\_batt}=I_{load}*V_{diode}$ (per channel)
  - Most datasheets give the V_{diode} as 650mV typical, 700mV maximum
  - Generally for loads currents <2A this is not a concern since the power dissipation will be < 1.5W
  - Generally for load currents >4A this must be checked since the power dissipation will be >3W
    - For such cases the reverse battery requirements such as ambient temperature and time duration must be known in order to calculate the max junction temperature.
  - If the power dissipation/junction temperature become too high during reverse battery conditions, IFX does offer chip on chip Hi-Current PROFET devices with ReverSave feature

PROFET+
Unique Selling Points

- After the device selection is optimized-- ***"Let's Seal the Deal"***
- PROFET+ Unique Selling Points:
    - Best in Class Short Circuit Robustness
        - Only device in market to specify in the datasheet 100K (min. 100K for +24V) cycles
    - Best in Class Quiescent/Leakage Current
        - Only device in market to specify <1uA for dual channel device (0.5uA max), very important for applications active during key off
    - Best in Class Current Sense Accuracy
        - Info Note has been released and datasheets are updated for dual channel devices with improved current sense accuracy specifications
        - For device nominal current range, 7-8% accuracy is specified
            - » This may be good enough to save customer a calibration step--$$$$
        - For single point calibration, 5% accuracy is specified
        - PROFET+ also has only one analog sense pin for dual channel device, internal multiplexer may save customer an external multiplexer

Advantages of Solid State Relays vs. Electromechanical Relays

Comparison between relay and Power PROFET^{TM} Device

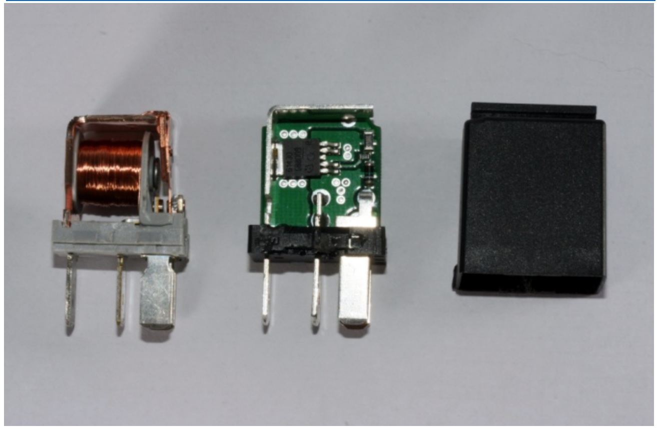
As already written, the Power PROFET^{TM} offers many advantages over the relays. Below is a short comparison between both devices regarding 3 main points of interest.

FUNCTIONALITY

Relay	BTS50015-1TAC
[illegible]	
1	100K
[illegible]	
Fuse box access	Full
[illegible]	
✗	✓

Solid State Relay: easy & direct replacement!

SOLID STATE RELAY (SSR)

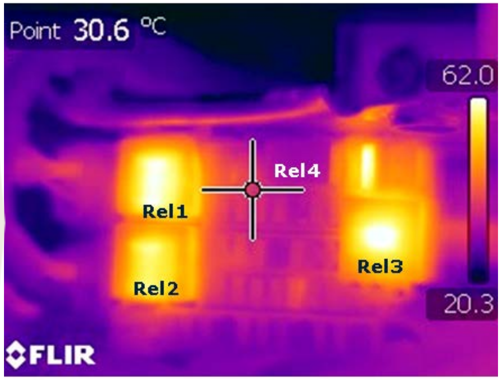


A Power PROFET™ can be embedded in a relay housing in order to offer an easy and direct replacement to the relay. Such a solution is known as a solid state relay and offers the same benefits as a semiconductor switch:

- Switching cycle improvement
- Current consumption reduction
- Power losses reduction

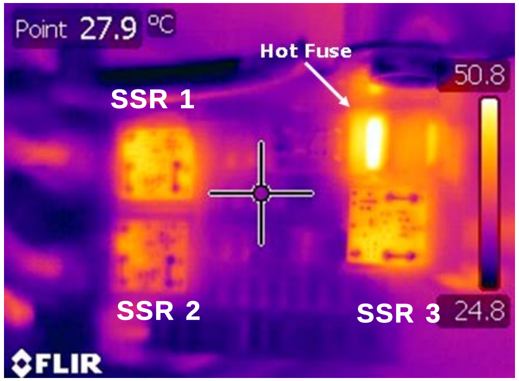
Example of direct relay replacement with SSR for a high current load : the rear defogger

Relay solution



Highest temperature	62°C
Relay temperature	62°C

SSR solution



Highest temperature	51°C
Device temperature	~37°C

25°C difference between relay and Power PROFET™

Less power losses = higher energy efficiency

Relay replacement on existing PCB
Relay replacement without architecture change

Moving driving stage from the relay box to the BCM

In most cases a relay can be replaced by a Power PROFET™ by simply moving the driving stage from a relay box to an existing BCM. There is no need for an extra PCB board !
Below is a non exhaustive list of loads which would have advantages to be driven by the Power PROFET™.

From relay to semiconductor

From relay box to existing PCB

Relay function		Benefits
	Starter relay	- Switching cycle capability - Improve integration
	Relay for high current DC load	- Reduce system temperature & power losses - Improve integration
	Relay for wiper	- Noiseless switching - Switching cycle capability
	Relay for pumps and motors	- Enable PWM driving - Reduce wire harness & system sizing
	Relay for Clamp15	- Remove fuses - Improve integration

For More Information:
Existing Arrow Customers: 800 777 2776
New Customers: 800 833 3557
www.arrownac.com/powermanagement